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Systematic Review of Functional Outcomes Following ACL Reconstruction with Quadrupled Hamstring Autograft

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A B S T R A C T

Background: Stability and functional restoration of the knee requires reconstruction surgery for injuries in the anterior cruciate ligament (ACL), which are frequent in people that are physically active. A popular strategy for attaining good functional results is quadruple hamstring autografts for arthroscopic reconstruction. This systematic study assessed functional results, range of motion, return to pre-injury activity status, postoperative stability, and complications related to quadruple hamstring autografts used in ACL reconstruction.

Methods: This review protocol was registered in PROSPERO with registration number CRD42025637560. A comprehensive search was done using the PubMed database through March 2024, employing specific search terms related to arthroscopic ACL reconstruction using a quadrupled hamstring autograft. The risk of bias was evaluated using the ROBINS-I tool, and only high-quality studies were included. Due to significant heterogeneity in methodologies and outcomes, findings were summarized narratively without meta-analysis. Data extraction and analysis were performed according to the PRISMA guidelines.

Results: Out of the screened studies, eight met the inclusion criteria, examining outcomes in ACL reconstruction using different graft types, such as autologous semitendinosus (ST), combined semitendinosus and gracilis (ST+G), and allogeneic fascia lata. Across studies, peak torque and total work did not significantly differ between graft types. For instance, Adachi et al. (2003) reported no significant differences in isokinetic strength between ST and ST+G groups at 60°/second and 180°/second. Nakamura et al. (2002) observed that the maximum active knee flexion angle was significantly lower in the ST+G group, showing reductions up to 80.2% ($p < 0.01$) relative to the contralateral side. Similarly, Tashiro et al. (2003) reported significantly lower torque in the ST+G group at 70° and 90° knee flexion ($p < 0.05$), emphasizing the impact of graft choice on deep knee flexion strength. Functional scores, including Lysholm and IKDC, showed minimal variance across graft types. For instance, Goyal et al. reported no significant difference in Tegner-Lysholm and IKDC scores between the all-inside tibial tunnel and complete tibial tunnel techniques ($p > 0.05$). Additionally, Streich et al. noted that knee stability was well-preserved in the ST-only group, with an average side-to-side laxity difference of 0.78 ± 1.85 mm using KT-1000 measurements ($p < 0.05$), demonstrating excellent stability in the long term.

Conclusion: The review presents helpful findings about the positive effects of quadruple hamstring autograft ACL reconstruction which includes better knee stability and increased range of motion capabilities and enhanced return to normal activity levels. The study demonstrates that knee flexion strength and angle are influenced by autograft versus allograft choice together with single versus multiple tendon extraction but stability along with functional outcomes stay mostly unaffected. The use of ACLR with ALLR as a combined procedure leads to better durability in meniscal repairs which supports long-term stability. This review shows tendon harvesting decreases flexion strength mostly when multiple tendons are used yet it provides essential guidelines for customized surgical planning and future research.

Keywords: Anterior Cruciate Ligament Reconstruction, Hamstring Tendons, Arthroscopy, Graft Survival, Treatment Outcome

INTRODUCTION

Active people are more prone to suffer from ACL injuries which mainly include sprains and rips. The principle objective of ACL reconstruction surgery (ACLR) is to help restore knee joint stability while enhancing function and returning patient ability to play sports. The knowledge about anatomical and kinematic aspects of ACL and enhanced surgical approaches has not eliminated residual rotatory instability cases among patients to less than 25%.[1] The treatment outcomes from this surgery become inferior while subjecting patients to increased risks of re-injury.[2] The knee joint's functional stability needs surgical ACL repair because early degeneration can otherwise occur. The natural ACL fails to heal well so reconstruction becomes the necessary treatment approach. When selecting a reconstruction graft it needs to duplicate the original structure and mechanical behavior of the native ligament despite any difference in exact duplicate characteristics after repair. The reconstructed tissue needs biological integration ability alongside low antigenic potential and enough biological capacity to merge with host bone.[3] Various graft alternatives can be opted for the ACL tear reconstruction. The two primary types of grafts are autografts, which comprise quadriceps, hamstrings, tibialis anterior and tibialis posterior, peroneal tendon, and Achilles, and allografts, which include bone-patellar tendon-bone (BTB), hamstring tendon, and tibialis anterior and tibialis posterior. The combination of low failure rates and absence of anterior knee pain gives hamstring tendon autografts a standing as one of the top choices for ACL reconstruction.[4]

The essential part of ACL reconstruction surgery involves hamstring tendon removal for the purpose of restoring knee structural stability and operational capabilities. Harvesting technique selection represents a critical factor that determines the level of surgical complications as well as treatment achievement. The anteromedial and posteromedial techniques represent the main procedures used in this process. Surgeons make an incision on the front side of the tibia tubercle midpoint for accessing the hamstring tendon during the anteromedial approach. The surgical access enables fast tendon entry but it results in damage to collateral ligaments and infrapatellar saphenous nerve near the treatment area. Doctors use OLIBAS to minimize treatment hazards from this operational method despite ongoing nerve damage concerns. The posteromedial approach involves an incision positioned above the palpable semitendinosus tendon within the posteromedial aspect of the knee. The posteromedial method gives doctors another access point to tendons which potentially decreases risks to nerves similar to those from anteromedial procedures. Techniques defined by Franz et al[4] and Kodkani et al[5] provide extensive alternatives and refinements for tendon harvesting. Research shows that these surgical approaches produce similar beneficial results regarding postoperative outcomes and healing process and patient contentment. The decision between anteromedial and posteromedial techniques for navigation depends on physician choice and patient factors as well as procedural objectives.[6]

After collection of the hamstring tendons, any remaining muscle fibers are carefully removed. The removal process varies depending on whether the semitendinosus tendon is used by itself or paired with the gracilis tendon. For constructing a quadruple-stranded semitendinosus graft (4-ST), a non-absorbable suture is threaded around the central segment of the folded tendon, securing both terminal ends together to achieve the required graft configuration. A process of double-folded middle graft placement occurs before suturing begins on top and descends to the suspensory mechanism. Throughout the tendon harvesting procedure the extracted tendons received fabrication on a suspensory device which formed their four-strand graft configuration. The tendons receive double-stranded stitches with non-absorbable thread to connect the lower to the upper parts and the upper to the lower parts of free ends.[4]

AIM

This review focuses on evaluating the success of autograft techniques used in arthroscopic ACL reconstruction following knee injuries. This research compiles and examines current scientific data to assess how well this surgical approach restores knee function and stability after damage to the anterior cruciate ligament.

OBJECTIVES

1. To evaluate the functional performance following arthroscopic anterior cruciate ligament reconstruction utilizing quadrupled hamstring tendon autografts.
2. To assess knee joint stability and overall range of motion following ACL repair with a four-strand hamstring autograft technique.
3. To analyze the rehabilitation timeline of arthroscopic ACL reconstruction with a quadrupled hamstring graft in relation to pre-injury physical activity and sports involvement.
4. To document the incidence of complications associated with ACL reconstruction using quadrupled hamstring autografts, including graft failure, postoperative issues, and re-injury.
5. To present a comprehensive overview of current evidence on clinical outcomes and procedural risks related to arthroscopic ACL repair using quadrupled autogenous hamstring tendons, aiding both clinical decision-making and future research.

METHODOLOGY

This review was conducted in adherence to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines.[7] This protocol has been registered with PROSPERO [Reg ID: CRD42024637560]. Five authors evaluated all eligible studies independently. In cases of discrepancies, a consensus was reached. The search for articles

was conducted through the electronic database PubMed, which was accessed up until March 2024, using specific search terms. These terms included "Arthroscopic anterior cruciate ligament reconstruction using quadrupled hamstring," "Arthroscopic Anterior Cruciate Ligament Reconstruction" and "Hamstring," and "Functional outcomes in Arthroscopic Anterior Cruciate Ligament Reconstruction." Thirty of the 1350 articles that were extracted from the PubMed database were chosen for in-depth examination following a rigorous screening procedure. The remaining articles were deemed irrelevant to the review's focus and excluded. The complete search strategy with findings is depicted in table 1.

Table 1: Search strategy and key words

Search Terms Used	Article Count
"Arthroscopic anterior cruciate ligament reconstruction using quadrupled hamstring"	41
"Arthroscopic Anterior Cruciate Ligament Reconstruction" AND "Hamstring"	572
"Functional outcomes in Arthroscopic Anterior Cruciate Ligament Reconstruction"	737

Inclusion criteria:

1. Research included practical results from arthroscopic ACL reconstruction utilizing quadrupled hamstring autograft.
2. Research employing quadrupled hamstring autograft as the preferred one for ACL reconstruction surgery.
3. Research evaluating postoperative stability, range of motion, return to the pre-injury activity level, and complications connected with quadrupled hamstring autograft ACL reconstruction.
4. Research published in peer-reviewed scientific journals.
5. Research accessible in the English language.
6. Research with accessible full-text articles.

Exclusion criteria:

In order to ensure that relevant studies are included in the systematic review on arthroscopic ACL reconstruction using quadrupled hamstring autograft and that studies that do not meet the specific focus and objectives are excluded, the following types of studies will be excluded: studies that lack sufficient data on functional outcomes or assessment scales; case studies without comparative data; studies that use grafts other than quadrupled hamstring autograft as the preferred one for ACL surgery; studies that are entirely focused on techniques or procedures unrelated to the ACL reconstruction using quadrupled hamstring autograft; studies that don't exist in the English language; and that lacks full-text accessibility; and studies that have redundant information.

These criteria were strictly adhered to, in order to ensure the inclusion of relevant studies and the exclusion of studies that did not meet the specific focus and objectives of this systematic review.

For the included studies, Cochrane Risk of Bias in Non- randomized Studies - of Interventions (ROBINS-I) tool [8] was utilized and the assessment studies was based on the seven domains influencing, Participant selection, intervention classification, missing data, deviations from intended interventions, measurement of outcomes and selection of reported results. The results were illustrated using traffic light plots and summary bar charts employing Cochrane Risk-of-bias visualization (Robvis) tool.[9] The traffic light plot employed green, yellow then red indicators to demonstrate low, moderate and high risk of bias within each domain. Most assessment areas showed low to moderate risk for bias while participant selection demonstrated occasional high bias points. The study used bar charts to present summary data about the distribution of noted biases throughout various studies. The potential biases were managed through stringent eligibility criteria in combination with consistency during data extraction and sensitivity tests when possible.

RESULTS

Characteristics of the Included Study:

The PRISMA flowchart is illustrated in Figure 1. It summarizes the process of systematic review for studies on arthroscopic anterior cruciate ligament (ACL) reconstruction with a focus on functional outcomes using hamstring grafts. Initially, 1,350 records were identified from a PubMed search using terms like "Arthroscopic anterior cruciate ligament reconstruction using quadrupled hamstring," "Arthroscopic Anterior Cruciate Ligament Reconstruction AND Hamstring," and "Functional outcomes in Arthroscopic Anterior Cruciate Ligament Reconstruction." After removing 38 duplicates, 1,312 records were screened, with none excluded at this stage. All 1,312 records were sought for retrieval and assessed for eligibility. Exclusions included 586 studies not reporting ACL reconstruction, 535 studies not focused on functional outcomes, and 181 with methodology or inadequate data. Ultimately, Eight studies [1,10–16] were included for the qualitative synthesis and in the final review. No reports were excluded due to overlapping populations. Figure 1 illustrates an overview of the study selection process.

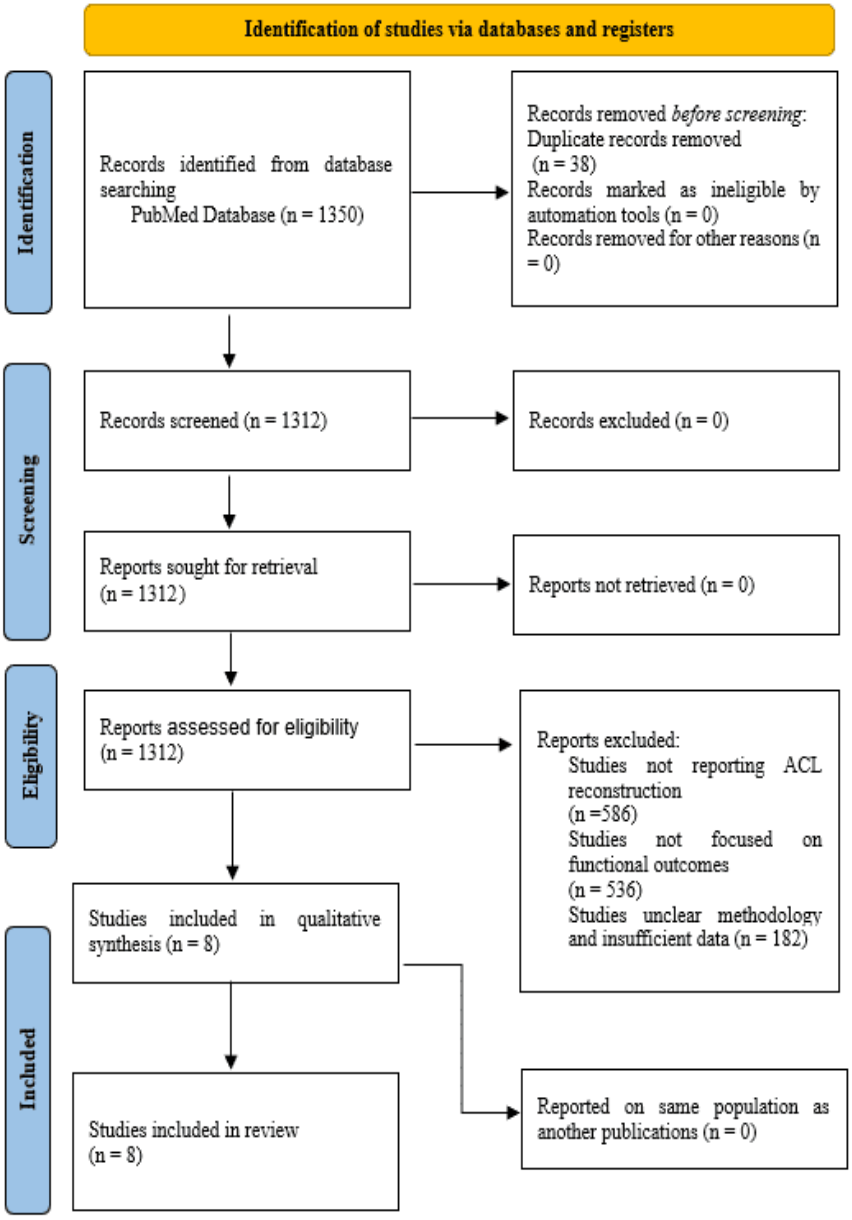

Figure 1: PRISMA flow Chart

The table 1 summaries the characteristics of the included studies, the information was procured from the studies with the help of a piloted Microsoft Excel sheet: the first author's surname with year of publication, Country of study, study design, diagnosis / clinical aspects of the cohort, number of participants (n) and Key findings of the study.

Table 2: Characteristics of the included studies

Study	Country	Study Design	Sample Size	Diagnostic/Clinical Aspects	Key Findings
Adachi et al., 2003[10]	Japan	Prospective Cohort	58	ACL Reconstruction	Harvesting hamstring tendons (ST or ST+G) for ACL reconstruction does not influence peak torque or total work but results in a impaired active knee flexion angle, especially with more tendon harvesting.
Nakamura et al., 2002 [11]	Japan	Case-Control	74	ACL Reconstruction	Flexion strength is lower in hamstring tendon-harvested limbs, particularly at deeper flexion angles (90°). Multiple tendon harvests (ST+G) further reduce active knee flexion range compared to ST-only harvest.

Tashiro et al. 2003[12]	Japan	Prospective, Randomized cohort Trial	85 patients (49 in semitendinosus only group, 36 in semitendinosus + gracilis group)	ACL reconstruction with autologous hamstring tendon grafts (semitendinosus alone vs. semitendinosus + gracilis)	Significant hamstring strength weakness at high knee flexion angles (≥70°) observed postoperatively, particularly in the semitendinosus + gracilis group. The gracilis tendon plays a role in maintaining knee flexor strength, especially at high angles. Weakness was more evident in prone position tests, suggesting that preserving the gracilis tendon may reduce morbidity in ACL reconstructions for athletes.
Streich et al., 2013 [13]	Germany	Retrospective Cohort Study	52	ACL rupture, underwent ACL reconstruction with semitendinosus autograft	At ten-year follow-up, excellent IKDC scores were reported, with no major flexion deficits (>10°). Only minor differences in knee laxity were observed compared to the contralateral knee.
Sonnery-Cottet et al., 2018[14]	France	Retrospective Comparative Study	383	ACL rupture with medial meniscal tear requiring ACLR and meniscal repair	Combined ACLR + ALLR reduced failure rates of medial meniscal repair compared to isolated ACLR (91.2% vs. 83.8% at 3-year follow-up), suggesting protective benefits of ALL reconstruction.
Goyal et al., 2022[1]	India	Prospective Comparative Study	80	Isolated anterior cruciate ligament (ACL) tear	The all-inside tibial tunnel technique resulted in reduced early postoperative pain and comparable functional outcomes to the complete tibial tunnel technique.
Konrath et al., 2016[15]	Australia	Cross-Sectional Study	20	ACL reconstruction using hamstring tendon grafts	Semitendinosus and gracilis muscle properties were significantly altered after tendon harvesting, contributing to strength deficits and asymmetry in knee muscles.
Ardern et al., 2010[16]	Australia	Retrospective Comparative Study	50	Post-ACL reconstruction with hamstring tendon harvest	No notable differences in hamstring strength recovery between ST and ST-G grafts; deficits of 3-27% persisted in hamstring strength compared to the non-operated limb.

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Risk of Bias:
The risk of bias assessment for the studies shown in figure 2 reveals a consistent presence of "moderate" bias (yellow circles) in several key domains. Most studies show moderate bias in "D1: Bias due to confounding" and "D2: Bias due to selection of participants," indicating potential issues with participant variability and confounding factors not being fully controlled. Additionally, "D5: Bias due to missing data" is another common area of moderate bias, suggesting incomplete data might have affected outcomes in some studies. However, low risk (green circles) is observed across all studies in "D3: Bias in classification of interventions" and "D4: Bias due to deviations from intended interventions," meaning these domains were generally well-handled. Despite these strengths, the overall risk of bias remains moderate (yellow) in most studies due to biases in participant selection, confounding, and missing data.

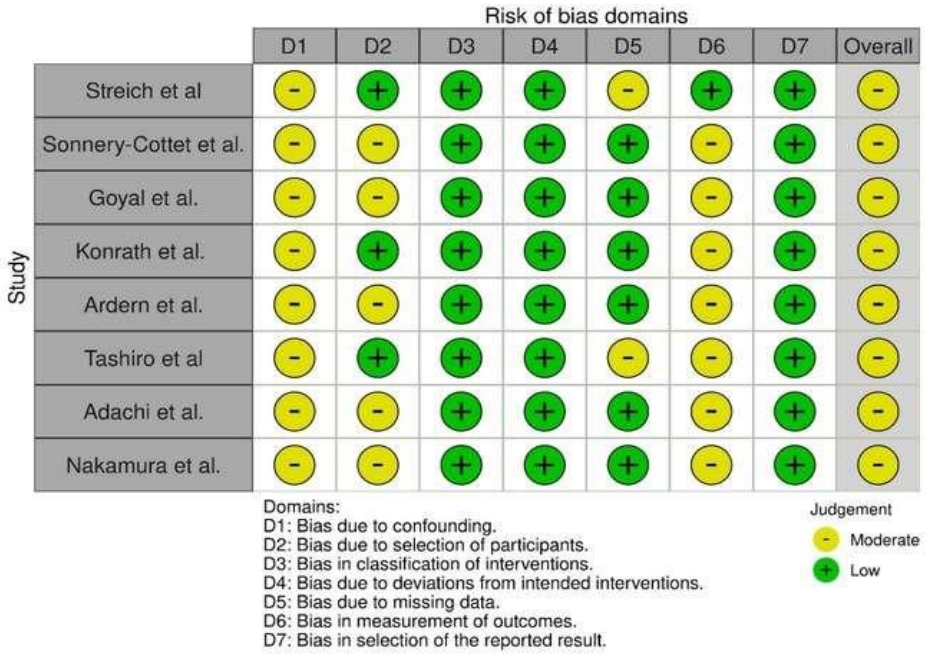

Figure 2: Traffic light Plots on the Risk of Bias for the included studies

The chart in figure 3 indicates that "bias due to deviations from intended interventions" and "bias in classification of interventions" were predominantly rated as low risk, suggesting that these areas were generally well-controlled. In contrast, "bias due to confounding" and "bias due to selection of participants" were rated as moderate risk across all studies, indicating potential limitations in these areas. "Bias due to missing data" and "bias in measurement of outcomes" presented a mix of low and moderate risk ratings, with some studies showing moderate risk. The overall risk of bias reflects a mix of low to moderate levels, highlighting areas for improvement in study design and reporting.

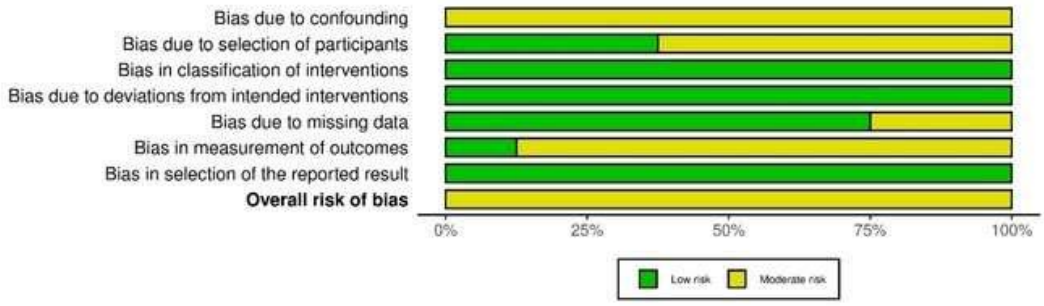

Figure 3: Overall risk of bias of the included studies

Isokinetic and isometric strength testing, knee flexion angle, and clinical evaluation in cases of ACL reconstruction surgery via different surgical techniques:

Table 2, Table3 and Table 4 summaries the isokinetic strength, Knee flexion angle and functional outcomes of various studies.

Adachi et al. (2003) [10] reported the effects of different graft types—specifically autologous semitendinosus (ST), combined semitendinosus and gracilis (ST+G), and allogeneic fascia lata—on postoperative hamstring performance in ACL reconstruction. In terms of isokinetic strength testing, the study found no significant differences in peak torque or total work between these groups at both 60°/second and 180°/second, indicating that knee flexion strength was largely preserved regardless of graft type. However, active knee flexion angle showed statistically significant reductions with increased tendon harvesting, with the ST+G group exhibiting a greater loss of flexion than the ST-only group, and the allogeneic fascia lata group experiencing the least loss of flexion. Clinically, all groups maintained their postoperative range of motion, with minimal functional impairment. These findings suggest that while harvesting multiple tendons affects knee flexion angle, it does not necessarily compromise overall clinical outcomes, although the authors recommend caution when using autografts in athletes requiring deep knee flexion.

The *Sonnery-Cottet et al.*[14] study assessed the results for patients who underwent insulated ACL reconstruction (ACLR) in comparison to those who combined ACLR with anteriolateral ligament reconstruction (ALRR). In the case of isokinetic and isometric power, no significant post -operative difference was found between isolated ACLR and ACLR + ALLR group, indicating equal power protection in both techniques ($p = 0.212$). Flexion angles in the knee were well preserved in both groups, without significant changes. Clinically, the study found that adding ACLR to ACLR was associated with a low failure rate for average Meniscal repair, 91.2% of the meniscus repair revolution after 36 months compared to 83.8% for separate ACLR group with ACLR + ALLR group was performed. In addition, Lysholm score was comparable between groups, an average of around 93.4. These findings suggest that the combined ACLR and ALLR provide a protective effect on meniscal repair, providing long -term stability in potentially high demand patients.

In *Streich et al.*'s study, the long term results of ACL reconstruction were evaluated as a ten-year follow-up through the use of a four-string semitendinosus late-auto force by reconstruction. For isokinetic power, the findings indicated only the smallest difference on the side of the stability of the knee, with the CT-1000 Arthrometer measurements, showing an average slack difference of 0.78 ± 1.85 mm compared to the contralateral side ($p < 0.05$). When it comes to the flexion angle of the knee, only one patient was presented more than 10 ° with a flexion deficit, suggesting the excellent protection of the speed limit with minimal impact on long -term flexibility. The clinical evaluation through the International Knee Documentation Committee (IKDC) scoring system revealed the beneficial functional results, usually postoperatively reinforced the efficiency of Semitendinosus -autographs for ACL reconstruction, while reporting the level of high stability and satisfaction with patients.

Statistical analysis from the Goyal et al.[1], showed that using all-inside tibial tunnel in ACL reconstruction diminished postoperative pain during the first six weeks because patients from this group scored lower on Visual Analogue Scale (VAS) at both two weeks and six weeks compared to patients with complete tibial tunnels. The patients in both groups showed improved functional outcomes according to Tegner Lysholm and International Knee Documentation Committee (IKDC) scores yet received comparable grades using these tests. Quadriceps muscle strength remained comparable between the groups at 6, 9, and 24 months, while hamstring strength showed higher values in the all-inside technique group during the follow-up period. Table 5 summaries the comparative strength and functional outcome from studies employing different techniques.

Konrath et al.'s[15] study provided in-depth statistical findings on isokinetic and isometric strength assessments after ACL reconstruction using hamstring tendon grafts. The results indicated that the harvested semitendinosus and gracilis muscles exhibited a significant reduction in volume and cross-sectional area (CSA), correlating with strength deficits in knee flexion. The deficits were more pronounced in cases where tendon regeneration did not occur. Although compensatory hypertrophy was observed in non-donor muscles like the biceps femoris, this adaptation only partially offset the knee flexor strength loss. Significant differences were found in peak torque and CSA between the surgical and contralateral limbs

Ardern et al.'s[16] retrospective study compared postoperative hamstring strength between patients who had ACL reconstruction with either a semitendinosus-only (ST) graft or a semitendinosus-gracilis (ST-G) graft. The analysis found no significant differences in isokinetic or isometric hamstring strength between the two groups at various knee flexion angles, including 30°, 90°, and 105°. Both groups demonstrated persistent hamstring strength deficits of 3% to 27% relative to the non-operated limb, despite the return to sports. The study also reported that the standing knee flexion angle should not be used as a surrogate measure for hamstring strength due to its weak correlation with isometric strength

Nakamura et al. (2002)[11] examined hamstring strength recovery and knee flexion angle after ACL reconstruction using either ST or ST+G tendon autografts. The study identified significant reductions in isokinetic knee flexion strength in both graft groups, with notable deficiencies at 90° knee flexion, where flexion torque was approximately 80.2% of the contralateral side in the ST group and 78.8% in the ST+G group at 60°/second. This effect was more pronounced in the ST+G group, suggesting that harvesting both tendons can further reduce deep flexion strength compared to harvesting the ST tendon alone. Additionally, the maximum active knee flexion angle was significantly lower in the ST+G group than in the ST-only group, indicating a greater loss of flexibility with more extensive tendon harvesting. Despite these strength and flexion angle limitations, clinical measures of knee stability (such as AP laxity measured by KT-1000) were comparable between the groups, with no significant side-to-side differences, suggesting that knee stability was maintained overall.

Tashiro et al. (2003)[12] examined the impact of two ACL reconstruction techniques—semitendinosus-only (St) versus combined semitendinosus and gracilis tendon harvest (StG)—on postoperative knee flexor strength. Using isokinetic and isometric testing, the study found significant hamstring strength reductions at high knee flexion angles (≥70°), particularly in the StG group. While both groups showed some strength recovery by 18 months, the StG group demonstrated consistently lower torque, especially at 70° and 90° flexion. Clinical outcomes, assessed via IKDC criteria and KT-1000 arthrometry, revealed similar knee stability and functional recovery between the groups, but the St group had slightly better strength results at higher flexion angles, crucial for activities requiring deep knee flexion. The study

suggests that preserving the gracilis tendon may provide an advantage in maintaining flexor strength, making the St technique potentially more suitable for athletes or individuals needing strong knee flexion post-surgery.

Table 3: Isokinetic strength comparison

Study	Graft Type	Isokinetic Strength (Flexion) Peak Torque	Torque Comparisons at Specific Angles	Key Findings
Adachi et al. (2003)[10**]**	ST, ST+G, Allogeneic Fascia Lata	No significant difference in peak torque	No difference at 60°/second and 180°/second	ST+G group showed greater loss of flexion angle; fascia lata group showed least flexion loss
Sonnery-Cottet et al.[14**]**	ACLR, ACLR+ALLR	No significant difference	Non-significant difference (p = 0.212)	Similar strength preservation in both techniques; ALLR addition showed lower failure in meniscal repairs
Ardern et al..[16**]**	ST, ST+G	No significant difference in flexion angles	Deficits of 3% to 27% across angles (30°, 90°, 105°)	Persistent hamstring strength deficits; return to sport observed in both groups
Nakamura et al. (2002)[11**]**	ST, ST+G	ST: 80.2%, ST+G: 78.8% of contralateral at 60°/s	More pronounced deficit at 90° flexion	ST+G group showed greater flexion strength loss
Tashiro et al. (2003)[12**]**	ST, ST+G	Lower torque in StG at high flexion angles (≥70°)	Torque deficits observed at 70° and 90°	ST-only technique better preserves knee flexor strength in deep flexion angles

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Table 4: Knee Flexion Angle Findings

Study	Graft Type	Knee Flexion Angle Loss	Clinical Outcome Measures	Key Findings
Adachi et al. (2003) [10**]**	ST, ST+G, Allogeneic Fascia Lata	ST+G had greater loss; least in allogeneic group	Range of motion maintained in all groups	Increased tendon harvest affects knee flexion angle; clinical outcomes unaffected
Sonnery-Cottet et al.[14**]**	ACLR, ACLR+ALLR	Well-preserved in both groups	Lysholm score: ~93.4, lower meniscal repair failure in ACLR+ALLR	Combined ACLR+ALLR provides protective effect on meniscal repair survival
Streich et al.[13**]**	ST (4-strand)	Minimal side-to-side flexion deficit (>10° in 1 pt)	IKDC scoring: high stability and satisfaction reported	Effective long-term knee stability and ROM preservation
Konrath et al.[15**]**	Hamstring Tendon Graft	Flexion loss associated with lack of tendon regeneration	Partial compensatory hypertrophy in biceps femoris	Strength deficits in knee flexion due to tendon volume reduction; some compensatory adaptation
Nakamura et al. (2002) [11**]**	ST, ST+G	ST+G showed greater max flexion angle loss	Comparable AP laxity between groups	ST-only grafts maintain greater flexibility; knee stability comparable
Tashiro et al. (2003) [12**]**	ST, ST+G	ST+G had more flexion angle loss in deep angles	IKDC criteria: similar stability in both groups	ST graft potentially better for deep knee flexion activities; better hamstring strength at high angles

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IKDC- International Knee Documentation Committee

Table 5: Comparison of Strength and Functional Outcomes by Technique

Study	Technique	Strength Outcome	Functional Outcome	Statistical Highlights
Goyal et al.[1]	All-inside vs. complete tunnel	Lower VAS scores for all-inside	Tegner-Lysholm and IKDC: no significant difference	All-inside showed significant pain reduction in early postoperative phase
Ardern et al.[16]	ST vs. ST+G	Persistent hamstring deficits (3%-27%)	Return to sports: both groups	No strength difference in flexion angles; weaker correlation with standing knee flexion

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ST-G - Semitendinosus and Gracilis Tendons
IKDC - International Knee Documentation Committee

DISCUSSION

This study was conducted as a systematic review rather than proceeding to a meta-analysis. The decision not to perform a meta-analysis was primarily due to the heterogeneity across the included studies. Variations in study design, patient demographics, surgical techniques, graft types, follow-up durations, and outcome measurement methods introduced significant variability, making it challenging to derive a cohesive and statistically meaningful pooled estimate. Additionally, the limited sample sizes in several studies and the inconsistency in reporting certain key outcomes, such as isokinetic strength and knee flexion angle, further limited the feasibility of a meta-analysis. As a systematic review, this study effectively synthesizes the existing evidence and highlights important trends and research voids, providing a valuable foundation for further research.

Isokinetic Strength testing:

When comparing the 2ST-2G and 4ST categories, Tashiro et al.[12] found a notable reduction in peak torque after six months, at the 180°/s angular velocity. The next 12 and 18-month evaluations revealed that this difference had vanished, and there had been no discernible change in the angular velocity at 60°/s. In the two angular velocities, no additional significant differences in the peak torques were found among the 4ST and 2ST-2G categories. Nakamura et al.[11] found no variations among the two categories in their investigation of the torques generated at 90° knee flexion angles for the two angular velocity. Conversely, the torque curves obtained at 60°/s were used by Tashiro et al.[12] to assess the torque at angles 70°, 90°, and 110° knee flexion. When comparing the 2ST-2G group to the 4ST group at all angles during the 18-month assessment, they discovered that the 2ST-2G group had a significant hamstring weakness (At 70° the contralateral was 80% for 2ST-2G and 90% for 4ST category; At 90° the contralateral was 75% for 2ST-2G and 85% for 4ST category; at 110° the contralateral was 70% for 2ST-2G and 82% for 4ST category) ($p<0.05$). Nevertheless, the lack of standard deviations made it impossible to compute the impact sizes and confidence levels of 95%.

In a meta-analysis and systematic review involving 1,109 cases, Chin BZ et al[17] found that using hamstring tendon autografts with the semitendinosus (ST) alone versus using both the semitendinosus and gracilis (ST-G) resulted in a reduced side-to-side shortfall in the isokinetic peak torques for monitoring 2 years. In particular, peak torques in flexion varied significantly between 60° /s ($p = 0.02$) and 180°/s ($p = 0.01$). Specifically, there was a significant difference in peak torque during flexion at 60 degrees/s ($p = 0.02$) and 180 degrees/s ($p = 0.01$). However, no notable variations were observed in the side-to-side changes in the anterior laxity ($p = 0.81$), or patient-observed effects in the IKDC ($p = 0.06$) and Lysholm scores ($p = 0.67$). Although recovery of knee strength after ACL reconstruction surgery is important, the use of hamstring tendon autografts may compromise the integrity of the hamstring muscles, potentially impairing internal tibial rotation with the gracilis tendon. The ST-G and ST categories' isokinetic peak flexion torques differed statistically from one another, yet the patient-reported outcome scores did not show any appreciable clinical differences. Surgical challenges with ST grafts, often falling short of optimal length, may require the addition of an additional gracilis tendon. Overall, while ST-alone grafts showed advantages over ST-G grafts in terms of isokinetic strength testing, these differences did not significantly impact overall knee function and physical activity. Sharma A et al.[18], conducted a meta-analysis of numerous trials that included isokinetic strength testing to determine whether to use the ST separately or with gracilis (ST-G) for hamstring tendon autografts in ACL restoration. Both 180 to 360 degrees per second and 60 degrees per second were used for this testing. While most studies revealed a trend in that direction, Yosmauoglu HB et al.'s

study[19] found a statistically notable drop in strength among the ST-G group at 60 degrees per second. Yet, the measurement of isokinetic strength at 180°/s to 300°/s did not reveal any appreciable variations between the two groups. Sensitivity analysis did not show qualitative variations in the results of isokinetic strength. Table 6 summaries all other studies describing on the IKDC score post ACL using hamstring not included in the study.

Isometric Strength testing:

In order to determine muscle strength, Tashiro et al.[12] (7) measured the maximal isometric knee flexion torques in both seated and prone postures at 70° and 90° angles. For every group, the measurements were expressed as the percentages of the contralateral limbs. Compared to the 4ST group, the 2ST-2G showed a notable decline in muscle strength at 18 months. In particular, in the prone position, at 70° the contralateral was 70% for the 2ST-2G and 80% for the 4ST and at 90° the contralateral was 60% for the 2ST-2G and 75% for the 4ST, and in the seated position, at 70° the contralateral was 80% for the 2ST-2G and 90% for the 4ST categories ($p < 0.05$).

Four tests on isometric strength were carried out by Sharma A et al.[18] (10); two of the studies (12, 13) included testing at flexion angles of 90 degrees, while the other two studies (14, 15) also included testing at flexion angles of 105 to 110 degrees. Two of these investigations revealed that the ST-G group's strength was reduced at high flexion angles and 90 degrees of flexion, respectively.

Knee Flexion angle:

After surgical procedures, Adachi et al.[10] and Nakamura et al.[11] measured the amount of active knee flexion loss by measuring the range of motion (ROM) while standing in a way that minimized the involvement of muscles by placing the hip and ankle in certain positions. At 12 and 35 months after surgery, notable variations in the flexion angle loss between the two groups were observed by Adachi et al. Similar to this, the 2ST-2G group had a much lower flexion angle loss at 24 months than the 4ST group[11] (8). It's vital to remember that a total of 4 studies were carried out, and 2 of them revealed that the ST-G group witnessed higher active flexion losses.

Table 6: Summary of other studies on IKDC score post ACL using hamstring not included in the study

Study	Key Findings
Soni S et al [20]	28.1% achieved excellent scores, 45.0% good, 26.7% fair, 0% unsatisfactory LGS
Christia et al [21]	90% excellent to good results - 87% restore to pre-injury activity level – Post-surgical hurdles: pain at the graft site, numbness, laxity, superficial infections
Sharma A et al [18]	No notable variations between groups in IKDC score and instrumented anterior laxity
Murray et al (2016) [22]	44% of BEAR patients achieved IKDC grade A, compared to 29% in the ACLR group - Higher hamstring strength in the BEAR group
Murray et al (2020) [23]	Positive outcomes observed in the BEAR group compared to ACLR, supporting the efficacy of the BEAR procedure
Micheli and Kocher [24]	Physeal-sparing nature suitable for Tanner I-II patients - Transitioning to hamstring grafts presents benefits - Reduced risk of growth disturbances with LET
Tavakoli DR et al [25]	SA-ACLR demonstrated significantly higher IKDC and Lysholm scores at 24 months compared to standard ACLR
Lee BI et al [26]	Patients with >20% tibial remnant showed better proprioception and functional outcomes compared to <20% remnant group
Vascellari A et al [27]	Hamstrings autograft favoured choice for ACL reconstruction - 63% of surgeons indicated preference for ALR in diagnosed instability cases - Common techniques summarized

ACL: Anterior cruciate ligament, ACLR: ACL reconstruction surgery, IKDC: International Knee Documentation Committee, BEAR: Bridge-enhanced ACL repair, SA-ACLR: Suture-augmented - ACLR, LGS: Lysholm gilquist scores, LET: Lateral Extra-Articular Tenodesis.

Functional Recovery and Patient Outcomes:

Soni et al.[20] reported favorable postoperative results, with 28.1% of patients achieving excellent Lysholm Gilquist Scores (LGS), 45.0% good scores, and 26.7% fair. No patients scored in the poor range, indicating successful functional recovery and a potential return to pre-injury activity levels. Christina et al.[2] found that 90% of patients had excellent to good outcomes, with 87% resuming previous activity levels post-surgery, although minor complications like site pain and mild laxity were noted.

Knee Laxity and Strength Tests

In six studies[10-12,28-30], knee laxity and functional abilities were assessed using the IKDC, SANE, Noyes, Tegner, and Lysholm scales, with no significant group differences in laxity or functional scores. Sharma et al.[18] found no discernible differences in instrumented anterior laxity between single (ST) and combined (ST-G) hamstring grafts, based on meta-analysis of multiple trials.

Innovative Techniques and Proprioception
Murray et al.[22] introduced the BEAR technique in 2016, using an organic sponge to improve ACL healing. In follow-ups, the BEAR group showed superior hamstring strength and IKDC scores compared to traditional ACLR groups. Micheli and Kocher's technique[24], and later Monaco's, provided a growth plate-sparing option suitable for younger patients. Lee BI et al.[26] found that preserving tibial remnants during ACL reconstruction improved proprioception, with patients with >20% remnant showing significantly better proprioceptive outcomes.

Enhanced Techniques and Surgeon Preferences
Tavakoli et al.[25] evaluated suture-augmented ACLR (SA-ACLR), finding higher IKDC and Lysholm scores in the SA group versus standard ACLR at 24 months ($P < 0.05$). Vascellari et al.[27] surveyed surgeons and found hamstring autografts to be widely preferred for ACL reconstruction, with 63% opting for anterolateral ligament reconstruction (ALLR) in cases of instability and the anteromedial portal as the favored method for femoral tunnel drilling.

The collective findings from these studies illustrate that various ACL reconstruction (ACLR) techniques yield generally positive outcomes, though with differences in functional measures, knee laxity, and recovery times. Lysholm and IKDC scores indicate favorable functional recovery across ACLR methods, with minimal postoperative complications. Notably, Suture Augmentation (SA) ACLR showed higher patient-reported outcomes (PROMs) but no significant impact on retear or DVT rates compared to standard ACLR. Hamstring autografts, particularly with single-bundle constructs, showed strength advantages in deep knee flexion, as opposed to combined semitendinosus-gracilis (ST-G) autografts, which had weaker hamstring strength and higher flexion angle losses. The BEAR technique showed promising functional outcomes and was superior in hamstring strength compared to traditional autografts.

Isokinetic and isometric testing at various angles suggested that ST-only grafts better preserved knee flexor strength at deep flexion angles, indicating their suitability for athletes. Knee flexion loss was often greater with ST-G grafts. However, while the choice of graft type impacts specific physical attributes like flexion strength, it does not appear to significantly affect overall knee function and patient satisfaction. Thus, technique selection should balance anatomical preservation with specific functional goals, especially for active patients.

The study's limitations include its sample size and diversity, which may restrict the generalizability of findings, especially if the participants lack demographic variety. Methodological limitations, such as potential biases from specific measurement tools or short observation periods, may affect result reliability. The narrow scope of analysis may overlook broader aspects, while uncontrolled confounding variables could weaken the findings' validity. Limitations in technology or data collection methods might further impact results. Future research could address these by increasing sample size and diversity, applying longitudinal designs to observe long-term effects, and adopting advanced mixed methodologies for a deeper, comprehensive view. Including additional variables to control for confounding factors and leveraging improved technology would enhance accuracy and applicability, enabling researchers to refine these findings across various settings.

CONCLUSION

This review and analysis of research on the results of quadruple hamstring autograft ACL restoration offer important new perspectives on the advantages and disadvantages of this surgical technique. The results indicate that this method produces positive functional outcomes, such as increased range of motion, knee stability, and resume to pre-injury activity levels. However, some variations and considerations must be acknowledged. Key findings demonstrate that while different graft types (e.g., autografts vs. allografts, or single vs. double tendon harvesting) impact knee flexion strength and active knee flexion angle, they generally preserve essential knee stability and clinical functionality. Specifically, the use of semitendinosus-quadruple hamstring grafts appears to offer better outcomes in preserving flexor strength at higher knee flexion angles, suggesting a potential advantage for patients with high functional demands, such as athletes.

Additionally, the study reveals that combining ACL reconstruction with anterolateral ligament reconstruction (ACLR + ALLR) can enhance the durability of meniscal repairs, indicating a synergistic effect that may improve long-term joint stability without compromising strength. Despite these encouraging findings, the study also highlights the trade-offs involved with tendon harvesting, particularly when multiple tendons are used, which may lead to greater flexion deficits. Clinicians are thus advised to consider these differences when planning ACL repairs, especially for patients who require optimal knee flexion for performance.

Future research should further explore these outcomes with larger, more diverse populations and investigate the long-term functional implications of these surgical choices. By refining our understanding of the biomechanics and functional outcomes of ACL graft options, this research contributes valuable knowledge to optimizing patient-specific surgical approaches and rehabilitation protocols.

Conflicts of Interest
The authors have declared that no competing interests exist.

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Ethical Approval
This study is a systematic review of previously published literature. No new human participants were involved, and thus institutional ethical approval was not required.

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